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Product Cycles, Innovation and Relative Wages in European Countries

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PRODUCT CYCLES, INNOVATION AND RELATIVE WAGES IN EUROPEAN COUNTRIES

ABSTRACT

This paper attempts to bridge the gap between the theoretical literature examining how innovation affects income across countries and the empirical literature examining how relative wages within a country change over time. We test the hypothesis that the relative wage between workers in high-and low-technology industries *within* a country is a function of the rate of domestic innovation *and* innovation abroad. To test this hypothesis data for 7 European countries for the years 1971-1988 are used. The empirical results show that the relative rates of innovation (as measured by the ratio of patents to high-tech workers) are significant determinants of the relative wage.

KEYWORDS: relative wage, innovation, product cycle, patents

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INTRODUCTION

Recent theoretical work has examined the implications of technological change and international trade among innovating countries, that is, how innovation affects the terms of trade and economic growth (see, for example, Grossman and Helpman, 1992, and Dinopoulos, 1992). This literature, however, has not discussed possible domestic redistributive effects of innovation, because the models have only one type of worker in each country. Nevertheless, even though it does not address possible effects of innovation on sectoral wage differences within countries, this theoretical literature suggests the importance of innovation in determining differences in wages across countries.

Recent empirical studies have tried to explain changing sectoral wage differentials, particularly in the 1980s.[1] While this research has attributed much of the shift to technical change, only Mincer (1991) has actually included a measure of innovative activity. Similarly, while the increase in the amount of trade worldwide has been thought to play a role in determining sectoral wage differentials, the empirical measures of external influences have generally been import-penetration ratios or changes in the trade balance. These variables may not capture the way in which trade in new technologies, in particular, could affect labor compensation. Thus, while these studies have been successful in explaining supply and demand shifts, they have been unable to directly address the current public policy debate regarding the role of international competition in high-technology industries in determining domestic relative wages. The work presented here attempts to bridge the gap between these somewhat divergent theoretical and empirical strands of research. We use the product-cycle model developed by Butler (1993), which allows for two sectors in each country: an innovating (high-technology) and non-innovating (low-technology)

[1]For studies of the relative wage for the United States, see, for example, Katz and Murphy (1992), and Mincer (1991). For a study that looks at the effect of technology on relative demand for labor, see Berman, Bound and Griliches (1994). For a study of relative wages for European countries, see OECD (1993) and Davis (1992).

sector. In addition, there are two types of workers, with the more skilled workers employed in the innovating sector and the lower-skilled workers in the non-innovating sector. Because each innovating country has a non-innovating sector, technology is eventually transferred from the innovating sector of a country to the non-innovating sector of both countries. The product-cycle model implies that the relative wage between workers in high- and low-technology industries *within* a country (hereafter called the domestic relative wage) is a function of not only the rate of domestic innovation but of innovation abroad as well. Hence, the competitiveness of a country's innovating sector relative to its foreign counterparts, as measured by the relative innovation rate, is thought to play a large role in determining the domestic relative (high-tech to low-tech) wage.

To test whether high-tech workers compete with each other internationally, we use data for seven relatively integrated European economies spanning the years 1971-1988. The data come from a recently created data set from the OECD that has consistent disaggregated manufacturing wage and employment data. The empirical results show that, while the product-cycle model does not provide an exactly suitable empirical specification, it does suggest which variables should enter a generalized empirical specification that fits the data reasonably well. Furthermore, the relative innovation rates (where innovation is measured by the number of high-tech patents per high-tech worker within a country) is a significant determinant of the relative wage. This result supports the product-cycle hypothesis that foreign innovation affects the *domestic* income distribution.

In attempting to focus directly on the role innovation plays in determining relative wages, we abstract from some interesting issues examined elsewhere. Thus we are unable, in great part due to data limitations, to identify supply and demand effects in determining relative wages. For a more complete description of relative wages on a microeconomic level for European countries, see Davis (1992) and OECD (1993).

The paper begins with a description of the formal model from Butler (1993). The complete model is presented in the appendix. The next section presents the data and highlights the hypotheses concerning the importance of innovation rates. The econometric methods and results follow. The paper concludes with a summary of the results.

THE MODEL:

<u>The Household Sector</u>:

Consumers have identical time-separable preferences, characterized by a standard intertemporal utility function. Consumers value both variety and quantity, as represented by the following instantaneous CES utility function:

$$(1)\quad u_t = [\int_{a=0}^{\Omega(t)} C(a)^{\theta}]^{\frac{1}{\theta}} da \qquad 0<\theta<1,$$

where:

$C(a)$ = consumption of good 'a.'

θ = weight consumers place on quantity relative to variety.

$[0, \Omega(t)]$ is the continuum of different varieties available at time t.

For notational convenience we order the different types of varieties in the following manner:

varieties in the low-tech sector $\in [0, \Omega_{\ell}(t)]$,

varieties in the high-tech sector in Country 2 $\in (\Omega_{\ell}(t), \Omega_{2h}(t)]$, and

varieties in the high-tech sector of Country 1 $\in (\Omega_{2h}(t), \Omega(t)]$.[2]

[2]Hereafter, the time notation will be suppressed.

To avoid the problem of diverging to infinite variety, some goods are assumed to go out of fashion and are no longer consumed (or produced).[3]. The number of varieties that goes out of fashion is given at any time by gN(t), where g is the parameter determining the rate at which goods go out of fashion, $0<g<1$, and $N(t) = \Omega(t) - 0$.[4] Because preferences are the same in both countries, 'g' is not country-dependent. Utility is maximized at each moment of time, given the variety available. Varieties are available from three sectors: the innovating sectors in the two countries, and in the low technology sector.[5]

Choosing low tech goods as a numeraire, normalizing on the price of low-tech goods, denoting relative prices and wages by upper case letters and solving results in the following demand functions:

(2) $C_{\ell a} = Y/Z. \qquad \forall a \in [0, \Omega_\ell]$

(3) $C_{1a} = P_{1a}^{-\epsilon}\, Y/Z \qquad \forall a \in (\Omega_{2h}, \Omega].$

(4) $C_{2a} = P_{2a}^{-\epsilon}\, Y/Z \qquad \forall a \in (\Omega_\ell, \Omega_{2h}].$

where:

$$Z = \int_{a=0}^{\Omega(t)} P_a^{1-\epsilon} da,$$

P_a = price of good 'a', $a \epsilon [0,\Omega]$,

[3]Not every good stops being consumed, as not all types of goods go out of fashion. Rather, some proportion of goods stop being consumed. Another approach would be to have quality cycles, where innovation takes the form of improvements in existing products. Quality cycles are generated using Cobb-Douglas utility, in which there can be no demand for uninvented products (see, for example, Grossman and Helpman, 1991a, 1991b). One recent exception is an unpublished work by Dinopoulos (1992), in which both quality and product cycles occur in an economy. The model, however, does not provide closed-form solutions for empirical implementation.

[4]To simplify the analysis, we assume an equal proportion of goods go out of fashion in each sector.

[5]Because the variety available in the low-technology sector is the same in both countries, the country subscript is suppressed.

ϵ = $1/(1-\theta)$ is the (constant) elasticity of substitution between any two varieties, and

Y = world income.

Production:

There are two types of workers: low-productivity workers, who can only work in the low-technology sector, and high-productivity workers, who can work in either the high- or low-technology sector. We assume returns to skill are zero in the low-tech sector so that if skilled workers are employed in that sector, they receive the same wage as the low-skilled workers. Workers are immobile internationally. The labor market is perfectly competitive and wages are flexible. The reservation wage is assumed to be sufficiently below the wage in the low-technology sector to ensure all workers are employed.

The High-Technology Sector:

All firms have identical innovation and production functions. Firms are product monopolists in the sense that they innovate different products, yet linear technology makes entry easy, thereby making demand elastic for any given good. Because technology is linear, the number and scale of firms is indeterminate. R&D is required for innovation to occur and any given variety is produced by a single firm. Skilled workers can work in either production or R&D (although compensation is the same irrespective of where they work in that sector). Technology transfer is costless and is proportional to the amount of variety available in the high-tech sector. There is free entry in innovation in the sense that any firm which hires R&D workers can innovate. The structure of the innovating sector is the same in both countries. All results are derived for Country One; the results for Country Two can be found by changing the country-specific parameters.

The firm solves for the optimal time path of variety by maximizing total discounted profits, given the price and output level for each good, which come out of a static maximization problem. The amount of R&D labor the firm hires determines the variety of goods it produces. Firms always have an incentive to innovate because they are always losing varieties, due to technology transfer and goods going out of fashion.

Defining N_{1h} as the number of varieties available at any time in the high-tech sector of Country One, the rate of change of variety in that sector is given by:

(5) $dN_{1h}/dt = i_1 L_{1h}^R - k_1 N_{1h} - gN_{1h},$

where

$N_{1h} = \Omega - \Omega_{2h},$

L_{1h}^R is the number of R&D workers hired,

i_1 is the productivity parameter associated with R&D workers in Country One, and

k_1 is the rate at which technology is transferred from the innovating sector in Country One to the non-innovating sector.

Production is characterized by constant returns to scale, and given by:

(6) $Q_{1a} = \alpha_1 L_{1a}^P, \quad \forall a \in (\Omega_{2h}, \Omega]$

where:

$\alpha_1 =$ the productivity parameter associated with high-technology workers in Country One, and

$L_{1a}^P =$ the number of high-tech workers employed in the production of good 'a' in the innovating good sector of Country One.

Because the innovation and production functions are linear with respect to the decision variables, the problem is solved for a representative firm and then aggregated. The problem is solved recursively: The production choice, subject to the demand function, is a static problem and solved first; the choice of R&D investment, and therefore the amount of variety, is dynamic and thus solved second. The solution to the static maximization problem is given by:

(7) $Q_{1a} = P_{1a}^{-\epsilon} Y/Z.$

(8) $P_{1a} = W_1/(\alpha_1 \theta).$

where W_1 is the wage paid to workers in the high-tech sector. Because the right-hand side variables in equation (8) do not change as 'a' changes, the price for all goods in this sector is the same; a markup over the wage.

Solving the dynamic optimization problem with calculus of variations yields the following optimality condition:

(9) $[W_1/r][(L_{1a}^{P})(1 - \theta)/\theta - (k_1 + g)/i_1] = W_1/i_1$

This condition requires firms to hire R&D workers just up to the point where the current cost of R&D exactly equals the discounted benefit of future production. Because each firm is the sole producer of a given variety, the firm earns monopoly profits. These profits, however, are just sufficient to cover the costs of R&D. If, for example, the benefits of R&D exceeded the costs, firms would demand more R&D workers or there would be more entrants in R&D. This would require hiring more R&D workers, which would, for the industry as a whole, drive up the wage and reduce profits. This would continue until the gap between benefits and costs was eliminated. At that point, equation (9) would once again hold.

Using the optimality conditions, the labor constraint that there is a fixed number of skilled workers and the stability properties of equation (5), we can solve directly for the steady-state variety and the allocation of production and R&D workers:

(10) $L_1^P = (r + k_1 + g)\theta L_{1h}/(k_1 + g + \theta r)$,

(11) $L_1^R = (1 - \theta)(k_1 + g)L_{1h}/(k_1 + g + \theta r)$,

(12) $N_{1h} = i_1(1 - \theta)L_{1h}/(k_1 + g + \theta r)$,

where L_{1h} is the total number of skilled workers in Country One.

The Low-Technology Sector:

The low-technology sector produces only goods for which technology is internationally available. This technology comes from the two innovating sectors. Thus, technology is transferred not only from one country to another, but between sectors within a country. Letting N_ℓ denote the number of varieties in the low-tech sector, equation (19) describes rate of change of variety in that sector.

(13) $dN_\ell/dt = k_1N_{1h} + k_2N_{2h} - g\, N_\ell, \qquad 1 > k_1, k_2, g > 0$,

where

k_2 is the technology transfer rate for Country 2,

$N_{2h} = \Omega_{1h} - \Omega_\ell$, and

$N_\ell = \Omega_\ell - 0$.

The steady-state solution for N_ℓ is given by:[6]

[6]This equation is a first order linear difference equation which asymptotically reaches a steady state. The equation is insensitive to changes in initial conditions.

$$(14)\quad N_\ell = \left[\frac{(1-\theta)}{g}\right]\left[\frac{i_1 k_1 L_{1h}}{k_1+g+\theta r} + \frac{i_2 k_2 L_{2h}}{k_2+g+\theta r}\right].$$

The production technology for low-technology workers is given by:

$$(15)\quad Q_\ell = \alpha_\ell L_\ell,$$

where α_ℓ is the productivity parameter associated with low-tech workers. Perfect competition in both the input and output markets, along with the same production technology in both countries and symmetric preferences, ensures the price of these goods are the same. In equilibrium, the real wage equals marginal product; that is:

$$(16)\quad P_\ell = W_\ell/\alpha_\ell.$$

THEORETICAL RESULTS

From the supply constraints and the steady-state solutions derived above, the domestic relative wage is given by:

$$(17)\quad W_1/W_\ell = (N_{1h}L_\ell/L_1^p N_\ell)^{1-\theta}(\alpha_1/\alpha_\ell)^\theta\ \theta$$

$$= \left[\frac{gL_\ell}{(r+k_1+g)\{\ [L_{1h}k_1/(k_1+g+\theta r)] + [(i_2/i_1)L_{2h}k_2/(k_2+g+\theta r)]\}}\right]^{1-\theta}(\alpha_1/\alpha_\ell)^\theta\ \theta.$$

One of the unique results of the model is given by the domestic relative wage between high- and low-technology workers within a country.[7] The model predicts that a relative increase in one country's

[7] For other results, see Butler (1993).

productivity in R&D has a positive effect on that country's domestic relative wage and a negative effect on the domestic relative wage of the other country. An increase in the relative productivity of R&D workers increases variety and therefore the demand for high-technology goods of that country. The increase in innovation also leads to an increase in variety in the low-technology sector in both countries, which increases the quantity demanded of these less-expensive goods. The effect of increased innovation in the high-tech sector dominates the demand effect in the low-tech sector of that country, and the relative wage increases. The increase in demand for goods from the low-technology sector of the other country, however, is not offset by any change in variety in its high-technology sector and its relative wage declines. Thus, the relative rate of innovation (or, more precisely, the relative productivity of R&D workers in the two countries) is a significant determinant of the wage differential within a country.

DATA AND EMPIRICAL SPECIFICATION

The Data

The data are annual for the period 1971-1988. Complete data are available for 7 European countries: France, the former West Germany, Italy, the Netherlands, Norway, Sweden, and the United Kingdom. Industries are classified as high-tech by their R&D intensity, as defined by the ratio of R&D to output (see OECD, 1986 for more detail). Wage and employment data are not available at the 3-digit International Standard Industrial Classification (ISIC) for the time period, so 2-digit classification was generally used. The one exception is fabricated metal products (ISIC 381), which has a very low R&D-intensity according to the OECD, but would be included in the high-technology industries if a strict 2-digit classification was used because ISIC 38 contains primarily high-technology sectors. Complete data are available for fabricated metal products, however, so it is included as a low-technology industry. As a result, the industries are classified as high- and low-tech as shown in Table 1.

Because of the breadth of two-digit industries, some lower-technology industries are included in the high-technology category. This misclassification is expected to bias the results against our hypothesis, because it increases the number of high-technology workers and should decrease the wage difference between the two types of workers.

Wage and employment data come from the OECD Structural Analysis Industrial Database, which is a new data set of internationally comparable data constructed by the OECD.[8] The employment data are essentially a head count of wage and salary workers. They are divided into high- and low-tech employment in each country by the R&D intensity of the industry as defined above.

The data used to calculate the wage gap between high- and low-tech workers are labor costs, which include the costs of employers payments for non-wage compensation such as medical coverage and pensions, and are the total wage bill for that industry for a year. This variable is summed over the industries in that sector and divided by the total number of workers in that sector within a country to get the wage bill per worker in each sector. The domestic relative wage is then the ratio of annual wages per worker in the high-tech sector relative to the low-tech sector. In the data, the domestic relative wage was greater than one for all countries in all years. The relative high-tech/low-tech manufacturing wage increased on average in the sample period (1971-1988) in the United Kingdom, France, Germany and Italy; it decreased on average in the Netherlands, Sweden and Norway. Figure 1 plots the relative wage for all seven countries. Italy had the largest gap between high-tech and low-tech wages throughout the sample period.

Because the innovation parameter in the model is a measure of the productivity of R&D workers, the proxy used is patents per worker, which is simply the number of patents in the high-tech sector divided by the number of high-technology workers in that country. Foreign innovation is proxied by the number of patents in the high-tech sector in the other six countries divided by the number of high-tech

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[8]For more information on the data and how it was created, see OECD (1992).

workers in the same six countries. Figure 2 plots the relative innovation rates for the seven countries. For Italy, the ratio of patents per foreign high-tech workers to patents per domestic high-tech workers was the highest throughout the sample. Norway, the smallest country, had the most variable relative innovation rate, due to lumpiness in the number of domestic patents. The variability is not sufficiently great to cause changes in the ranking of Norway's innovation rate relative to other countries, however.

Finding an appropriate empirical measure of product innovation is difficult and has been extensively discussed in the literature. Using patents as a proxy may be insufficient because many goods are not patented. Nevertheless, patents do provide a means of measuring the degree to which the production rights of products or processes are exclusive. In general, patents have been found to be a good indicator of unobserved inventive output (see, for example, Griliches, 1990). The other proxy available is R&D expenditures. R&D data are available from the OECD for each country, but disaggregated industry-level data available are incomplete. In addition, not all R&D results in innovation. Patent data also have the advantage of being available over a long time horizon and in great detail and represent the output from R&D deemed to have economic value.

One problem with using patents is that patent laws vary across countries, whereas we want a consistent measure of innovation within an industry. To alleviate this problem, we use patents filed in the United States.[9] These are available at the three-digit Standard Industrial Classification (SIC) level from the U.S. Patent and Trademark Office.[10] Foreign patent data are highly correlated with both domestic patenting and R&D intensity, minimizing the costs of choosing one over the other.[11]

[9] As suggested by Zvi Griliches in conversation. In addition, see Soete and Wyatt (1983) for a discussion of using foreign patenting for an international comparison of innovation.

[10]These were converted into ISIC using the concordance study by Jim Kristoff at the Bureau of Census.

[11]See Soete and Wyatt (1983). For a discussion on the use of patents as an indicator of innovative activity, see Griliches, Pakes and Hall (1987), and Griliches (1990).

The parameters characterizing obsolescence, utility, and technology transfer are assumed to be the same across time. The obsolescence and utility parameters are the same across countries in the theoretical model and no good measures exist for use as proxies. At present, no empirical measure of technology transfer exists, so any differences in the rate of technology transfer across countries is captured by fixed effects in the panel data.

Another parameter from the theoretical model, production worker productivity, presents some challenges for the empirical work. Labor is the only input in the theoretical model, but for empirical purposes a measure of productivity within each sector is needed. While no perfect measure exists, we use value-added per high-technology worker divided by value-added per low-technology worker to at least partially account for differences in worker productivity across countries and time.

The Empirical Examination

Equation (17) is manipulated to have the form of a panel-data regression equation, which leads to several statistical tests of hypotheses related to the model. A maintained assumption is that the rate of technology transfer is the same across countries in equation (17), so that $k_1 = k_2$. We can then write the relative wage as

$$(18) \quad \frac{W_{1h}}{W_{1\ell}} = \phi\ (\alpha_1/\alpha_\ell)^\theta \left[\frac{L_\ell}{L_{1h}+(\frac{i_2}{i_1})L_{2h}} \right]^{1-\theta},$$

where

$$\phi = \theta \left[\frac{g(k+g+\theta r)}{(r+k+g)k} \right]^{1-\theta}.$$

Rearranging the right hand side of equation (18) and taking logs, we obtain for Country 1

$$(19)\quad \ln\left(\frac{W_{1h}}{W_{1\ell}}\right) = \ln(\phi) + \theta \ln(\alpha_1/\alpha_\ell) + (\theta-1)\ln\left(\frac{L_{1h}}{L_\ell} + \frac{i_2}{i_1}\frac{L_{2h}}{L_\ell}\right)$$

where subscripts h and ℓ denote the high-tech and low-tech industries, respectively. L_{2h} denotes employment in high-tech industries in the "rest of the world," i.e., the other six countries, L_ℓ is worldwide low-tech employment, and i_2 denotes the innovation rate in rest of the world. Equation (19) suggests that the relative endowments of high-tech to low-tech workers worldwide is a primary determinantof the relative high-tech to low-tech wage rate in a given country. Furthermore, equation (19) suggests that the numbers of high-tech workers should be weighted by a measure of relative innovation productivity before aggregating across countries. Recalling from equation (1) that θ is a parameter between zero and one, the model predicts a negative regression coefficient equal to $(\theta$-1) in equation (19).

Equation (19) highlights several possible explanations of why the domestic relative wage varies across countries. To illustrate the key hypothesis of this article, assume that two countries, say France and Italy, have identical relative endowments of high-technology workers and that France has a higher innovation rate than Italy. The notation

$$\left(\frac{i_2}{i_1}\right)_{FRA}$$

indicates the innovation rate in the rest of the world relative to that in the home country when France is the home country, because the subscript 1 stands for home country and 2 for rest of world. The model predicts that in France the wage premium for high-tech workers will be higher than in Italy, assuming that ϕ from equation (19) is the same in the two countries:

$$\text{When } L_h^{FRA} = L_h^{ITA} \text{ and } \left(\frac{i_2}{i_1}\right)_{FRA} < \left(\frac{i_2}{i_1}\right)_{ITA}, \text{ then } \left(\frac{w_h}{w_\ell}\right)_{FRA} > \left(\frac{w_h}{w_\ell}\right)_{ITA}$$

In the data analysis, however, we do not necessarily expect to be able to explain idiosyncratic reasons why a given country has a particular gap between high- and low-tech wage rates, so we allow for fixed effects in each country. We also allow for the possibility that innovation rates and domestic and foreign labor supplies do not interact strictly according to the specification in equation (19) in determining the domestic relative wage. Thus, the rigid functional form implied by the theoretical model is relaxed, although we test some restrictions implied by the theoretical model of (19). Consequently, the last term on the the right-hand side variable from equation (19) is divided into components that isolate, for example, the effects of the relative innovation rate and the domestic high tech/low tech labor endowment on the domestic relative wage:

$$(20) \quad \ln\left(\frac{L_{1h}}{L_\ell}+\frac{i_2}{i_1}\frac{L_{2h}}{L_\ell}\right) = \ln\left(\frac{L_{1h}}{L_{1\ell}}\right)+\ln\left(\frac{L_{1\ell}}{L_\ell}\right)+\ln\left(\frac{i_2}{i_1}\right)+\ln\left(\frac{L_h}{L_{1h}}\right)$$

with a remainder on the right-hand side, expressed as a Taylor's series expansion, equal to

$$\left(\frac{L_{1h}}{L_h}\right)\left(\frac{i_1}{i_2}-1\right) - \left(\frac{L_{1h}}{L_h}\right)^2\left(\frac{i_1}{i_2}-1\right)^2 + \ldots.$$

Table 2 lists the variables of the full model. In the estimation, all explanatory variables, X1-X5, are lagged to avoid simultaneity bias.

The pooled time-series and cross-section data set is estimated by maximum-likelihood, allowing for both autoregressive and cross-sectionally correlated errors. The autoregressive component is removed by quasi-differencing the data, with a different AR coefficient for each country. The error covariance matrix is obtained, conditional on the values of the regression coefficients and AR coefficients, by putting

$$(21) \quad \sigma_{ij} = \frac{1}{T} \sum_{t=1}^{T} u_{it} u_{jt}$$

into the covariance matrix, where u_i and u_j are the error vectors for countries i and j. Country-specific means are swept out of the error vectors, so the number of degrees of freedom used to calculate the t-statistics and probability values is reduced accordingly.

Table 2 contains the parameter estimates for the panel data set. In overall fit, the model (with quasi-differenced data) achieves an R-squared of .710.[12] The importance of the foreign innovation rate, relative to the domestic rate, in determining *domestic* wages is the most novel empirical finding. The significantly negative coefficient on the percentage gap between the rest-of-world and domestic innovation rates (X3) conforms with the prediction of the product-cycle model and suggests that countries that do not innovate well relative to their competitors have a smaller wage premium in the high-technology sector.

The strict product-cycle specification of equation (19), in which X1-X5 have identical, negative coefficients, clearly does not hold, however. In fact X1, X2 and X4 have significant, positive coefficients, whereas X3 and X5 have negative coefficients. The positive coefficient on X1 implies that high-tech wages have tended to increase even as the relative number of high-tech workers have increased. This suggests that workers of various types should not be viewed as exogenously given factor endowments. Instead, it appears that, on average, an outwardly shifting demand curve for high-tech

[12]This R-squared is measured from the quasi-differenced data with country means swept out. Hence, significant country intercepts and autoregressive parameters do not contribute at all to the R-squared; all of it is due to the regression coefficients, thereby maintaining the convention that the R-squared would be zero if all regression coefficients are zero.

workers led to endogenous increases in the number of high-tech workers and in their wages. Essentially, increases in demand appear to dominate increases in the supply of high-tech workers, so changes in the supply of domestic skilled labor are positively correlated with their wages. This result is consistent with studies done for the United States (e.g. Katz and Murphy, 1992), as well as a recent study from the OECD (1993).

Recalling that country-specific means have been swept out of the variables, X2 and X4 represent a country's share of total low-tech workers and inverse of the share of high-tech workers, respectively, relative to the mean shares. Thus, if a country's share of low-tech workers rises above its mean level, then that country's labor force has had to absorb a relatively large number of low-tech workers compared with other countries and the low-tech wage falls relative to the high-tech wage. This absorption hypothesis explains the observed positive coefficients on X2 and X4, although it does not form part of the basic product-cycle model. The product-cycle model provides a steady-state equilibrium domestic relative wage, without dynamics explaining what happens in the short run when a country's low-tech labor force grows more rapidly than its neighbors.

For the variable X5 [equation (20)], the terms in the Taylor series expansion will converge quickly to zero, because in no case does a country's innovation rate exceed one by an amount greater than the reciprocal of that country's share of total high-tech workers. For this reason, X5 should be viewed as an interaction variable between the innovation rate and the share of high-tech workers, i.e., the first term of the expansion. The negative sign, which was implied by the model, suggests that the combination of a high innovation rate and a relatively small number of high-tech workers to absorb has a synergistic effect in raising the high-tech wage premia above that implied by each factor separately.

The gap in value-added per worker across the two sectors has the expected positive sign: As the gap between the value added by high-tech and low-tech workers widens, the relative wage of high-tech workers increases. Another variable we investigated as a proxy for production worker productivity was fixed-capital investment per high-tech worker divided by fixed-capital investment per low-tech worker, but the coefficient was not significant and it was not included in the empirical model.

The AR coefficients in Table 2 show that Norway appears to have a unit root, but this does not invalidate the estimation procedure. The presence of the unit root simply implies that we fully difference the Norwegian variables, rather than quasi-difference.

CONCLUSIONS

This paper uses industry-level data on European manufacturing firms to provide empirical tests of several propositions regarding domestic relative high-tech/low-tech wages stemming from a product-cycle model. The most novel empirical finding is the importance of foreign innovation in the high-tech sector in determining the domestic relative wage. While there has been much rhetoric surrounding the effects of increased competition in high-technology industries, these results demonstrate how foreign innovation can empirically affect wages in high-technology industries. This result is particularly strong given the level of aggregation we were required to use, which is likely to bias the results against our hypothesis. We find if high-tech workers in competing countries begin to innovate more rapidly relative to domestic high-tech workers, then the relative wage between domestic high- and low-tech workers tends to decline. Similarly, if domestic high-tech workers innovate faster, then, ceteris paribus, the percentage gap between domestic high- and low-tech workers will increase. The latter result is consistent with the results of Mincer (1991) for the United States and provides more rigorous support for the argument discussed by Davis (1992) and elsewhere that domestic proficiency in technological innovation plays a role in determining domestic relative wages.

Future research could expand the data set to include the United States, Canada and Japan. Because trade as a share of GDP is considerably smaller for the United States than the other countries in the sample, it would be interesting to test whether foreign innovation has as large an impact on domestic high-tech/low-tech wages in the United States as it does in other countries.

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APPENDIX

THE HOUSEHOLD SECTOR

Infinitely-lived consumers have identical time-separable preferences, characterized by the following intertemporal utility function:

$$\text{(A1)}\quad V = \int_0^{\infty} e^{-rt}\, u(.)dt,$$

where r is the constant consumers discount rate and u(.) is the instantaneous utility function, which is a CES utility function given by:[13]

$$\text{(A2)}\quad u_t = [\int_{a=0}^{\Omega(t)} C(a)^{\theta}]^{\frac{1}{\theta}} da \qquad 0<\theta<1,$$

where:

C(a) = consumption of good 'a.'

$[0,\Omega(t)]$ is the continuum of varieties available at time t.

For notational convenience we order the different types of varieties in the following manner:

varieties in the low-tech sector $\in [0,\ \Omega_{\ell}(t)]$,

varieties in the high-tech sector in Country 2 $\in (\Omega_{\ell}(t),\ \Omega_{2h}(t)]$, and

varieties in the high-tech sector of Country 1 $\in (\Omega_{2h}(t),\ \Omega(t)]$.[14]

[13]This utility function, taken from Dixit and Stiglitz (1977), has the property that all goods of the same prices are valued the same.

[14]Hereafter, the time notation will be suppressed.

Preferences are assumed to be the same for all individuals in both countries, so this function is treated as an aggregate utility function, but prices are considered parameters as if the utility function were maximized for each individual and then aggregated. With these preferences, individuals consume all goods that are produced. Utility is maximized at each moment of time, given the amount of variety available in the two high-technology sectors (determined via firm optimization below) and in the low-technology sector.

Consumers value both quantity and variety, which is captured by the parameter θ. The closer θ is to 1, the more consumers value quantity relative to variety. To avoid the problem of infinite variety, we assume some goods go out of fashion. As a result, consumers cease consuming a certain percentage of goods each period. The number of varieties that goes out of fashion is given at any time by $gN(t)$, where g is the parameter determining the rate at which goods go out of fashion, $0<g<1$, and $N(t) = \Omega(t) - 0$.[15] Because preferences are the same in both countries, 'g' is not country-dependent.

To determine the aggregate demand functions for goods, utility is maximized subject to world income.[16] Perfect competition in both the input and output market for low-technology goods, combined with the same production technology in both countries and symmetric preferences, ensures that the price of these goods are the same.[17] From the first order conditions, the relative demand between high- and low-technology goods is:

[15]To simplify the analysis, we assume an equal proportion of goods go out of fashion in each sector.

[16]World income is defined as the sum of all labor income. The demand functions are linear with respect to income and can be aggregated across individuals.

[17]For simplicity, transportation costs are assumed to be zero. Because the variety available in the low-technology sector is the same in both countries, the country subscript is suppressed.

(A4) $\frac{C_a}{C_\ell} = \left[\frac{p_a}{p_\ell}\right]^{-\epsilon}$ $\quad \forall\ a \in (\Omega_\ell,\ \Omega],\ \forall \ell \in [0,\ \Omega_\ell],$

where $\epsilon = 1/(1\text{-}\theta)$ is the (constant) elasticity of substitution between any two varieties.

Choosing low-tech goods as the numeraire, normalizing on the price of low-tech goods and denoting relative prices and wages by upper case letters and solving results in the following demand functions:

(A5) $C_\ell = Y/Z.$

(A6) $C_{1a} = P_{1a}^{-\epsilon}\ Y/Z \qquad \forall a \in (\Omega_{2h},\ \Omega].$

(A7) $C_{2a} = P_{2a}^{-\epsilon}\ Y/Z \qquad \forall a \in (\Omega_\ell,\ \Omega_{2h}].$

where:

$$Z = \int_{a=0}^{\Omega(t)} P_a^{1-\epsilon} da$$

P_a = price of good 'a', $a \epsilon \Omega$, and

Y = world income.

PRODUCTION

Only skilled workers can be employed in the high-tech sector. These workers can be employed in R&D or in production of high-tech goods. Skilled workers receive a higher wage when employed in the high-technology sector (the wage is the same irrespective of where they work in that sector), but can work in either the high- or low-technology sector. Returns to skill are assumed to be zero in the low-technology sector, so if skilled workers are employed in the low-technology sector, they receive the same wage as the low-skilled workers. Low-skilled workers can only work in the low-technology sector. Workers are immobile internationally. The labor market is perfectly competitive and wages are flexible.

The reservation wage is assumed to be sufficiently below the wage in the low-technology good sector to ensure all workers are employed.

HIGH-TECHNOLOGY SECTOR:

All innovating firms within a country have identical innovation and production technology, although they are product monopolists in the sense that they innovate different products. Innovation at any point in time is a function of the number of R&D workers, and a firm produces each innovation until the technology is transferred to the low-technology sector or the variety go out of fashion. Technology transfer is costless and is proportional to the amount of variety available in the high-technology good sector. This could occur when production becomes standardized. Another interpretation is that the production technology of a product is transferred when its patent expires.

Production technology is linear with constant returns to scale.[18] As a result, the number of firms is indeterminant. The structure of the innovating sector is the same in both countries. All results are derived for Country One; the results for Country Two can be found by changing the country-specific parameters.

The firm solves for the optimal time path of R&D workers by maximizing total discounted profits, given the price and output level for each good. The amount of R&D labor the firm hires determines the variety of goods it produces.

The rate of change of variety for the innovating sector of Country One is given by:

(A8) $dN_{1h}/dt = i_1 L_{1h}^R - k_1 N_{1h} - gN_{1h},$

where

$N_{1h} = \Omega - \Omega_{2h},$

[18]To keep the production sector simple (since it is not the primary focus of the model), the production and innovation technologies are linear. Although this is somewhat restrictive, it also has the advantage of providing results that are estimable.

i_1 is the productivity parameter associated with R&D workers in Country One,

k_1 is the rate of technology transfer for Country One, and

L^R_{1j} is the number of R&D workers in that sector.

Let firms be indexed such that N_{1j} is the measure of the set of firm j's contribution to variety and is the distance of the interval $|\Omega_{1j} - \Omega_{1j-1}|$, where Ω_{1j}, $\Omega_{1j-1} \in (\Omega_{2h}, \Omega]$. Then the law of motion that determines the firm's contribution to variety in the innovating sector of Country One is the same for all firms and given by:

$$\text{(A8}'\text{)} \quad dN_{1j}/dt = i_1 L^R_{1j} - k_1 N_{1j} - gN_{1j}; \qquad 0<i_1<1,\ 0<k_1<1,$$

where L^R_{1j} is the number of R&D workers in firm j.

Production is characterized by constant returns to scale, and given by:

$$\text{(A9)} \quad Q_{1a} = \alpha_1 L^P_{1a}, \qquad \forall a \in (\Omega_{2h}, \Omega]$$

where:

$\alpha_1 =$ the productivity parameter associated with high-technology workers in Country One, and

$L_{1a}{}^P =$ the number of high-tech workers employed in the production of good 'a' in the innovating good sector of Country One.

Because the innovation and production functions are linear with respect to the decision variables, the problem is solved for a representative firm and then aggregated. The problem is solved recursively: The production choice, subject to the demand function, is a static problem and solved first; the choice of R&D investment, and therefore variety, is solved second.

The Firm's Static Production Problem

The demand for any good 'a', $a \in (\Omega_{2h}, \Omega]$, is given by equation A6. The problem facing the firm is to maximize the following profit function subject to equations A6 and A9:

(A10) $\max_{Q_{1a}} \quad \Pi = P_{1a}Q_{1a} - W_1L^P_{1a} - W_1L^R_{1a},$

where

W_1 = the wage for high-skilled workers in the innovating sector of Country 1, and

$L_{1a}{}^R$ is the number of R&D workers used to innovate good 'a'.

Because the production decision occurs after R&D costs have been incurred, R&D costs are treated as sunk costs.

Solving for the profit-maximizing level of output gives:

(A11) $Q_{1a} = P_{1a}^{-\epsilon}Y/Z.$

Substituting in and solving for the profit-maximizing price yields:

(A12) $P_{1a} = W_1/(\alpha_1\theta),$

These equations hold for any product a ϵ $(\Omega_{2h}, \Omega]$, and because none of the variables on the right-hand side of (A12) change as 'a' changes, the price of any good produced by this firm will be the same; a constant markup over the wage. In fact, because all firms have the same production technology, the price charged by all firms in the innovating sector of Country One is the same.

<u>The Firm's Dynamic R&D Problem</u>

Firm j maximizes the following:

(A13) $\max_{L^R_{1j}} \quad \int_0^\infty e^{-rt}[P_1\alpha_1L^P_{1j} - W_1(L^P_{1j}+L^R_{1j})]dt,$

subject to equations A8', A11 and A12, the initial condition that there are no high-tech goods without R&D ($N_{1j}(0) = 0$), and:

$L^P_{1j} = N_{1j}L^P_{1a}$, and

r = producers' discount rate, which is assumed to be the same for both countries and equals the consumer's discount rate.

With substitution, equation A13 can be rewritten as:

$$\text{(A14)} \quad \max_{N_{1j}} \int_0^\infty e^{-rt}[\beta N_{1j} - \gamma(dN_{1j}/dt)]dt,$$

where

$\beta = W_1[(L^P_{1a})(1 - \theta)/\theta - (k_1 + g)/i_1]$, and

$\gamma = W_1/i_1$.

Solving for Euler's necessary condition for an optimum yields the following condition:

(A15) $\beta/r = \gamma$, which is equivalent to

$$[W_1/r][(L^P_{1a})(1 - \theta)/\theta - (k_1 + g)/i_1]=W_1/i_1$$

This equilibrium condition, which holds for the industry overall, requires that the current cost of R&D (γ) is exactly offset by the discounted benefit of future production (β/r).

To determine steady-state variety and the allocation of production and R&D workers, A8' is set to zero and solved for N_{1h}.[19] Assuming that all skilled workers are employed in the high-tech sector[20],

[19] Because the amount of variety is bounded by the number of skilled workers, variety is asymptotically stable and converges for all values of the parameters.

[20] This is true if the relative wage is greater than 1.

applying the aggregate labor constraint for skilled workers provides the following steady-state allocations of production and R&D workers and variety in the innovating sector:

(A16) $L_1^P = (r + k_1 + g)\theta L_{1h}/(k_1 + g + \theta r)$,

(A17) $L_1^R = (1 - \theta)(k_1 + g)L_{1h}/(k_1 + g + \theta r)$,

(A18) $N_{1h} = i_1(1 - \theta)L_{1h}/(k_1 + g + \theta r)$,

where L_{1h} is the total number of skilled workers in Country One.

Each innovating firm chooses how many R&D and production workers to hire, given the production and innovation technology. For the sector as a whole, this decision involves a tradeoff because of free entry and the aggregate labor supply constraint. Firms have to take into account the temporary state of their monopoly, because some goods go out of fashion and the production of high-tech goods are continually being transferred to the low-technology sector. As a result, innovation occurs in the steady state. Free entry ensures firms have to charge the competitive price and earn zero long run profits. On the demand side, consumers also face a tradeoff between consuming a greater quantity of goods (characterized by θ) or having greater variety available (given by $1-\theta$). Thus, in the steady state, the tradeoff between production and R&D workers, and therefore quantities and varieties, is the fundamental tension that keeps the equilibrium at its steady-state values.

THE LOW-TECHNOLOGY SECTOR

The low-technology sector produces only goods for which technology is internationally available. This technology comes from the two innovating sectors. Thus, technology is transferred not only from one country to another, but between sectors within a country. Defining N_ℓ as the number of variety in the low-tech sector at time t, equation A19 describes the rate of change of variety in non-innovating sector:

(A19) $dN_\ell/dt = k_1N_{1h} + k_2N_{2h} - g\ N_\ell, \qquad 1 > k_1, k_2, g > 0,$

where

$N_\ell = \Omega_\ell$, and

k_j is the rate at which technology is transferred from the innovating sector in country j to the non-innovating sector.

Substituting in the steady-state values of N_{1h} and N_{2h} into equations A19 yields the steady-state solution for N_ℓ, given by:[21]

$$\text{(A20)} \quad N_\ell = \left[\frac{(1-\theta)}{g}\right]\left[\frac{i_1\ k_1\ L_{1h}}{k_1+g+\theta r} + \frac{i_2 k_2\ L_{2h}}{k_2+g+\theta r}\right].$$

Production in this sector occurs in a perfectly competitive input and output market in the sense that free entry and constant average costs ensure zero profits. The production technology for low-technology workers is given by:

(A21) $Q_\ell = \alpha_\ell L_\ell,$

where α_ℓ is the productivity parameter associated with low-tech workers. In equilibrium, the real wage equals marginal product; that is:

(A22) $P_\ell = W_\ell/\alpha_\ell.$

[21]This equation is a first order linear difference equation which asymptotically reaches a steady state. The equation is insensitive to changes in initial conditions.

TABLE 1

HIGH TECHNOLOGY INDUSTRIES		
ISIC	350	Chemical products
	382	Non-electric machinery, office and computing equipment
	383	Electrical machines
	384	Transport equipment
	385	Professional goods
LOW-TECHNOLOGY INDUSTRIES		
ISIC	310	Food, beverages and tobacco
	320	Textiles, apparel and leather
	330	Wood products and furniture
	340	Paper products and printing
	360	Non-metallic mineral products
	370	Basic metal industries
	381	Metal products

TABLE 2

Y	$= \ln(W_1/W_\ell)$ The domestic relative wage
X1	$= \ln\left[\dfrac{L_{1h}}{L_{1\ell}}\right]$ domestic high, low-tech labor
X2	$= \ln\left[\dfrac{L_{1\ell}}{L_\ell}\right]$ domestic, world low-tech labor
X3	$= \ln\left[\dfrac{i_2}{i_1}\right]$ rest of world, domestic innovation
X4	$= \ln\left[\dfrac{L_h}{L_{1h}}\right]$ world, domestic high-tech labor
X5	= remainder term [equation 20]
VAL	$= \ln\left[\left[\dfrac{VAL_{1h}}{L_{1h}}\right] / \left[\dfrac{VAL_{1\ell}}{l_{1\ell}}\right]\right]$ value added

TABLE 3: PARAMETER ESTIMATES FOR FULL MODEL*			
Variable	**Coeff.**	**Stand. Error**	**Prob.Value**
AR coefficient: France	.690	.103	.000
AR coefficient: W. Germany	.882	.039	.000
AR coefficient: Italy	-.418	.265	.059
AR coefficient: Netherlands	.118	.199	.277
AR coefficient: Norway	.990	.189	.000
AR coefficent : Sweden	-.162	.203	.213
AR coefficient: UK	.783	.111	.000
X1: domestic high/low-tech labor	.160	.046	.000
X2: domestic/world low-tech labor	.498	.040	.000
X3: ROW/domestic innovation	-.089	.019	.000
X4: world/domestic high-tech labor	.462	.045	.000
X5: remainder term	-.624	.022	.000
VAL: high/low-tech value added	.207	.022	.000

*Note: Dependent variable is high-tech/low-tech wage.
All explanatory variables are lagged.

Figure 2
Relative Innovation Rates:
Foreign to Domestic

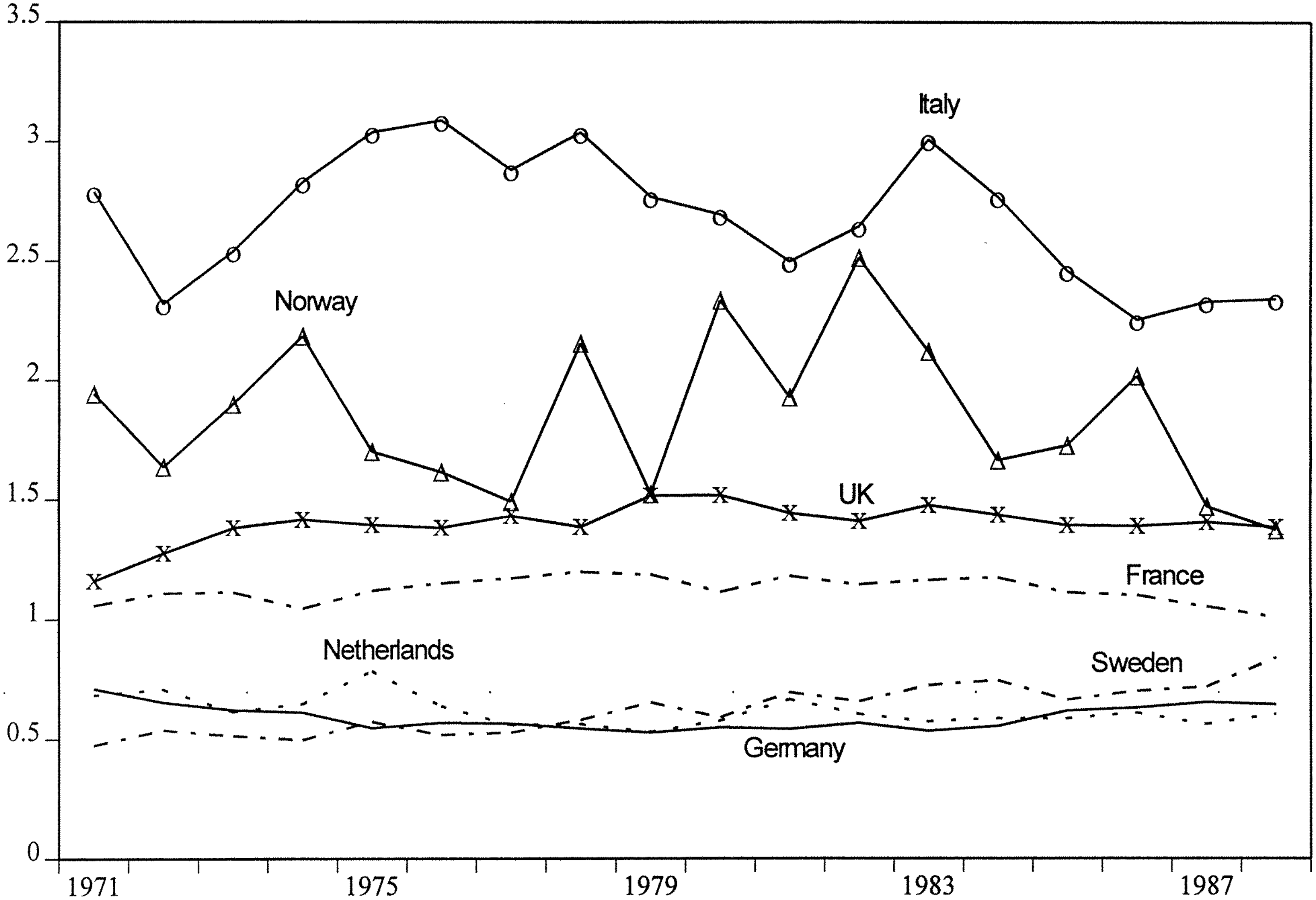

Figure 1
Relative Wages: High-tech to Low-tech